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Published in:
Scripta Metallurgica et Materialia

DOI:
[10.1016/0956-716X\(94\)90609-2](https://doi.org/10.1016/0956-716X(94)90609-2)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
1994

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Mol van Otterloo, J. L. D., & Hosson, J. T. M. D. (1994). Laser Treatment of Aluminium Copper Alloys: A Mechanical Enhancement. *Scripta Metallurgica et Materialia*, 30(4). [https://doi.org/10.1016/0956-716X\(94\)90609-2](https://doi.org/10.1016/0956-716X(94)90609-2)

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LASER TREATMENT OF ALUMINIUM COPPER ALLOYS: A MECHANICAL ENHANCEMENT

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(Received October 15, 1993)
(Revised November 15, 1993)

Introduction

Aluminium-copper alloys are commonly used as structural components for the car and aircraft industry [1]. They combine low density, high strength, high fracture toughness and good machinability. In commercial alloys, several other alloying elements (such as magnesium, manganese and silicon) are applied in combination with heat treatments to improve these properties [2].

Moreover, the strength [3] and wear-resistance [4] of the surface of alloys are improved by a high power laser beam. In this way the molten surface will be self-quenched by conduction of heat into the bulk. This technique ensures solidification velocities of 0.01-1 m/s. These high solidification velocities have a significant influence on the size and distribution of the morphology [5]. The hardness is related to the cell size (d) according to $d^{-\alpha}$ in which α may vary between 1/2 in the Hall-Petch relation [6] to 2 in laser treated Al-Si [7].

This work concentrates on Al-Cu alloys, in which the Cu content ranges between 0-40 wt.%, and is aimed at describing the mechanical and microstructural properties of these alloys upon variation of the laser scan velocity in the range of 0.0125 to 0.125 m/s.

Experimental

Al-Cu alloys containing 0, 5, 10, 15, 20, 30, 33 and 40 wt.% Cu are produced by melting the 99.999% pure components of the material with an arc-furnace. This technique has the following advantages. Melting of the fast oxidizing aluminum takes place in an inert argon environment and the samples will be well homogenized. The vacuum container, in which the whole process takes place, is brought to an atmosphere of 10^{-4} Pa and flushed with argon several times. Hereafter the container is at 0.8×10^5 Pa argon pressure and a subsidiary arc is lit. This subsidiary arc melts a piece of titanium, which acts as an oxygen

getter. Then the main arc is lit the material, which rests in a water cooled bed and between a tungsten point. This main arc acts as the cathode, while a tungsten point functions as the anode. Due to large temperature gradients between the top and bottom of the molten material, large convection currents will enhance homogenization after cooling. The Al-Cu alloys, so obtained, have a button like shape with dimensions: 7 cm in diameter and 1 cm thick.

These samples are flattened and sandblasted to obtain an equal, rough, and well-absorbing surface before laser treatment. After ultrasonic cleaning, the samples are irradiated by the use of a transverse flow Spectra Physics 820 CW-CO₂ laser under a protective argon atmosphere. At the surface the power of the laser beam is 1300 W. The focus point of the Zn-Se lens, with focal length of 127 mm, is 5 mm above the surface, resulting in a spot diameter of 0.175 mm. Moreover, single tracks are made at laser scan velocities, as stated above, at least 0.5 cm apart [8].

As natural age hardening is known to have an important effect on heat-treated materials [9], the samples are not used for mechanical and microstructural investigation for a period of four weeks, during which the hardness of Al-Cu increases in time due to the formation of a series of different precipitates. Precipitation starts with the formation of GP-zones followed by the θ' , θ [10].

After this four week-period, Vickers hardness measurements are carried out on samples sectioned as shown in figure 1a. Optical and scanning electron microscopy (SEM) in combination with energy-dispersive X-ray spectrometry (EDS) and backscattered electron imaging (BSE) are carried out on these polished samples. A similar process is carried out on samples sectioned as shown in figure 1b. For optical and scanning electron microscopy some samples are etched with a 10 ml HF, 15 ml HCl, 25 ml HNO₃ and 950 ml H₂O etchant.

Results

Hardness versus laser scan velocity is listed in table 1 with their mean standard deviations. A linear [2] increase in hardness is shown for the bulk hardness with increasing Cu weight content of the alloys, as depicted in figure 2. The lowest hardness for the pure Al: 21 HV and the highest for the hypo eutectic Al 40 wt.% Cu alloy: 212 HV. From figure 3 it is clear that the hardness increases in a logarithmic way [11] with increasing laser scan velocity. The slopes, at which this increase takes place, rise with augmenting Cu contents. Each hardness value consists of at least five measurements for the laser tracks and at least eight measurements for the bulk.

In order to understand the mechanical behavior of the materials, it is necessary to investigate their microstructural features. To begin with, in figure 4, an optical micrograph taken at a cross section transverse to the laser track and longitudinal to the surface, shows how the solidification front has progressed through the material. An abrupt change in the microstructure between the laser track and bulk is observed in all samples. This boundary is often less than 5 μ m wide (figure 5). The micrographs clearly show the refined structure in the laser tracks compared to the bulk. One of the important microstructural features is that the distance between the Cu rich material (bright contrast) decreases significantly

TABLE 1. Hardness [Vickers 0.1 kgf].

Sample	Laser scan velocity [cm/s]											
	0		0.125		0.395		1.250		3.953		12.500	
Al 0 wt.% Cu	21.0 ± 1.1	21.0 ± 1.1	21.0 ± 1.1	21.0 ± 1.1	21.0 ± 1.1	21.0 ± 1.1	21.0 ± 1.1	21.0 ± 1.1	21.0 ± 1.1	21.0 ± 1.1	21.0 ± 1.1	21.0 ± 1.1
Al 5 wt.% Cu	50.1	3.5	70.8	2.3	68.8	0.5	68.5	0.7	69.9	0.6	77.4	1.0
Al 10 wt.% Cu	78.7	1.1	91.9	1.7	100.1	1.7	107.4	0.7	114.0	2.1	123.0	0.5
Al 15 wt.% Cu	112.7	1.7	119.8	1.7	127.4	1.3	136.0	1.1	152.2	0.5	172.6	3.8
Al 20 wt.% Cu	132.3	5.9	148.0	4.0	163.5	1.4	176.9	2.2	186.6	4.3	206.0	4.8
Al 30 wt.% Cu	173.6	11.1	209.4	8.0	253.4	7.2	295.3	13.7	319.9	14.8	388.4	15.1
Al 33 wt.% Cu	182.8	6.5	232.2	3.7	300.0	12.5	349.9	3.2	366.3	3.3	414.9	10.0
Al 40 wt.% Cu	212.1	5.8	261.7	3.1	311.5	11.9	387.3	15.0	398.9	5.7	469.2	17.5

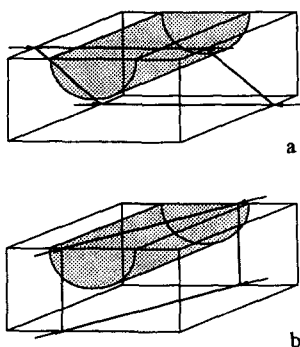


FIG. 1. a) Transverse and b) longitudinal sectioning of the samples with respect to the laser scan velocity.

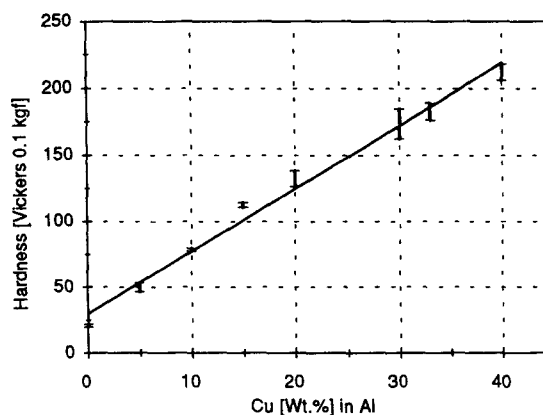


FIG. 2. Hardness vs. Cu concentration in non heat-treated Al-Cu alloys.

with increasing the Cu content. In an Al 10 wt.% Cu alloy this distance is about 1 μm (figure 6) compared to about 0.1 μm in an Al 33 wt.% Cu alloy (figure 7). The appearance of the brighter areas change from a cellular to a lamellar network with increasing the Cu contents. This lamellar network is oriented perpendicular to the solidification front.

As can be expected, the BSE-technique showed that the homogeneity of the alloys was sustained after melting the Al and Cu compounds with an arc furnace. EDS, on the other hand, is not an adequate method by which homogeneity can be tested. After all, the diameter of the interaction volume for electron excited characteristic X-rays in Al-Cu alloys is about 5 μm , which is in the same order of magnitude as the 5-15 μm islands and

dendrites of Cu rich material precipitating in the alloys. The pure θ phase was recognized in the bulk with EDS only in the Al 40 wt.% Cu alloy. In all the other alloys it appears in an eutectic-like structure throughout the samples. However, with respect to laser tracks, EDS measurements showed a homogeneous distribution of Cu, as the structure is much finer.

Discussion

An increase of Cu in Al-Cu alloys is accompanied by an increasing hardness in the bulk. In the first place, this proceeds from the harder θ phase. Mondolfo, for instance, indicates a hardness four times higher than conventional heat-treated Duralis [2]. The increase in the amount of the θ phase is accompanied by an increase in brittleness. This can be inferred from the microcracks detected through SEM.

Secondly, the θ phase appears in an Al-Al₂Cu eutectic lamellar structure. This eutectic composition is formed in the Al matrix. However in the Al 40 wt.% Cu alloy, islands of more or less pure Al₂Cu are found, while the matrix displays a eutectic-like structure. As the volume fraction of the eutectic structure increases, the mobility of dislocations in the material decreases. In this respect one has to consider that the lamellar spacing is in the order of 1 μm .

However, the increase in hardness due to laser treatment should be explained by a combination of the following phenomena. Firstly, a refinement in structure occurs, causing an increase in hardness [7]. This increase must also be explained by the change in the type of network which the Cu rich phase exhibits: cellular to lamellar (6 and 7). As soon as this change in network is realized, the slope between Vickers hardness and the laser scan velocity in figure 3 rises considerably. Other authors [12] showed by TEM that the interlamellar spacing (λ) decreases with increasing laser scan velocities and solidification rates (v_s) according to the $\lambda^2 v_s = \text{constant}$ theoretical relationship predicted by Jackson and Hunt [13]. As this spacing decreases, the hardness will increase due to a greater immobility of dislocations.

Secondly, the high quench rates, which can be attained by laser processing, will cause a larger fraction of the available Cu to be retained in solid solution [9]. Also, as mentioned earlier, precipitation starts with the formation of GP-zones followed by the θ'' and θ' phase. In this precipitation sequence, hardness will increase due to coherency loss between the precipitates and the Al matrix causing the matrix to be highly strained. On the other hand, hardness will decrease due to the larger spacing between the precipitates. The maximum hardness in conventional alloys will thus be associated with a combination of θ'' and θ' [14]. Nevertheless, during formation of GP-zones, as well as θ'' and θ' phases in the laser-treated alloys, the distance between these precipitates will be constrained by the refined cell size. Together with solid solution hardening, the decreasing cell size will contribute to an increase in hardness.

Finally, the increasing slopes in figure 3 are correlated with the Cu content in the alloys. As the amount of Cu increases, the thermal conductivity will rise, more or less proportionally, and as a consequence the quench rates. Both refinement in structure and

solid solution hardening will become more easy, thereby causing a faster increase in hardness.

Conclusions

The hardness of Al-Cu alloys can be boosted by an increase in the Cu content. The hardness values found in this work are well beyond the values which have, till now, been found. Earlier, we reported a hardness of about 110 Vickers hardness for a Al 2024 alloy treated with comparable laser scan velocities [9]. The findings presented in this paper, on the other hand, testify that a Vickers hardness of around 470 can be reached, if an Al 40 wt.% Cu alloy is treated with a laser scan velocity of 0.125 m/s.

As has been pointed out, the increasing hardness of the alloys as the Cu content increases is explained by the θ phase. This phase is found in an eutectic-like structure throughout the bulk of the alloys. The increase in hardness due to the laser treatment can be explained by refinement of structure and solid solution/ precipitation hardening effects. Both phenomena become more important as the Cu content increases and consequently the quench-rates.

Acknowledgments

This work is part of the research program of the Foundation for Fundamental Research on matter (FOM-Utrecht), and has been made possible by financial support from the Netherlands Organization for Research (NWO-The Hague).

References

- [1] F. King, Aluminium and its Alloys, Ellis Horwood Limited, Chichester (1987).
- [2] L. F. Mondolfo, Aluminum Alloys Structure and Properties, Butterworth, London (1976).
- [3] H. J. Hegge, J. Th. M. De Hosson, Proc. 2nd. Europ. Conf. Laser Treatment of Materials, Bad Nauheim, FRG, 13-14 Oct. 1988, DVS, bnd. 133, pp 160-163.
- [4] H. Haddenhorst, E. Hornbogen, H. W. Vollmer, Proc. 2nd. Europ. Conf. Laser Treatment of Materials, Bad Nauheim, FRG, 13-14 Oct. 1988, DVS, bnd. 133, pp 97-99.
- [5] P. A. Molian, J. Mat. Sci. Lett. **4**, pp 265-267 (1985).
- [6] E. O. Hall, Proc. laser Phys. Soc. B, **64**, 742 (1951); W.J. Petch, J. Iron Steel Inst. **173**, 25 (1953).
- [7] H. J. Hegge and J. Th. M. De Hosson, Acta Metall. **38**, 2471 (1990).
- [8] H. J. Hegge and J. Th. M. De Hosson, Scripta Metall. **38**, 2471 (1990).
- [9] J. Noordhuis and J. Th. M. De Hosson, Acta Metall. **41**, 1989 (1993).
- [10] D. A. Porter and K. E. Easterling, Phase Transformations in Metals and Alloys, Van Nostrand Reinold, London (1981).
- [11] E. Voce, J. Inst. Metals, **74**, 537 (1984).
- [12] S. C. Gill, M. Zimmermann and W. Kurz, Acta Metall. **40**, 2895 (1992).
- [13] K. A. Jackson and J. D. Hunt, Trans. Am. Inst. Min. Engrs. **236**, 1129 (1966).
- [14] J. M. Silcock, T. J. Heal and H.K. Hardy, J. Inst. Metals, **82**, 239 (1953-1954).

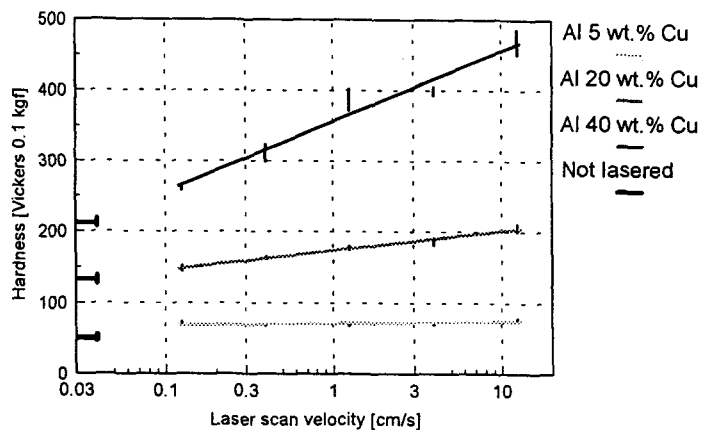


FIG. 3. Hardness profile as a function of the laser scan velocity and Cu contents.



FIG. 4. Optical micrograph of an etched Al 20 wt.% Cu sample laser scanned at a velocity of 3.953 cm/s.

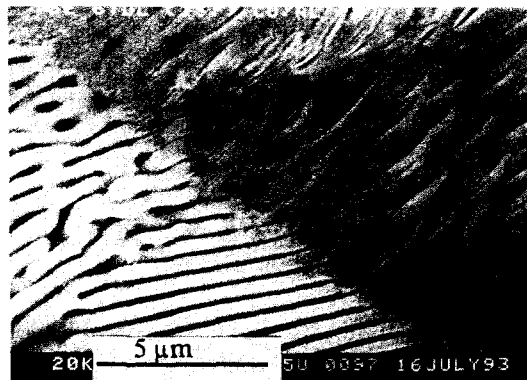


FIG. 5. SEM micrograph of an etched Al 30 wt.% Cu sample laser scanned at a velocity of 12.5 cm/s.

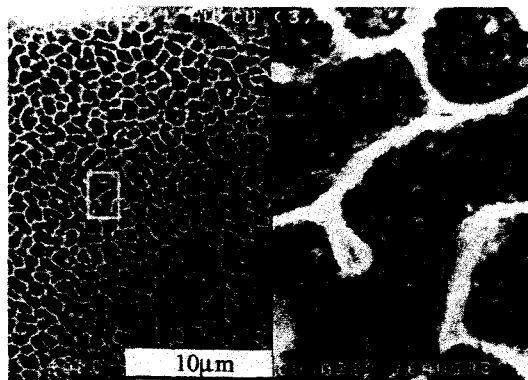


FIG. 6. SEM micrograph of an etched Al 10 wt.% Cu sample laser scanned at a velocity of 3.953 cm/s.

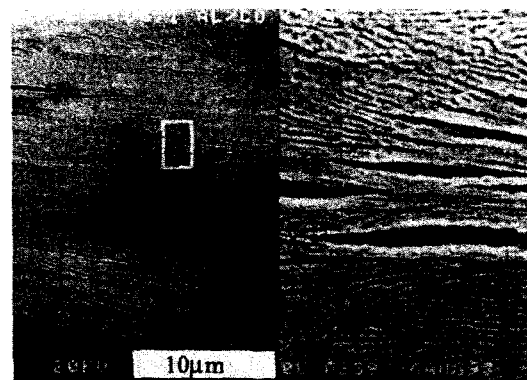


FIG. 7. SEM micrograph of an etched Al 33 wt.% Cu sample laser scanned at a velocity of 3.953 cm/s.